

Phase-Shift Enhancement by Mode-Suppression Techniques

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ABSTRACT

An X-band study has been made of a ferrite phase shifter consisting of a ferrite rod filling the waveguide height and subject to an axial (longitudinal) applied magnetic field. The phase shift produced by this configuration depends on the relative contributions of positive and negative phase-shift "modes," each of which dominates in a given section of the ferrite-loaded waveguide.

Initial results indicate that the relative phase shift of the plain ferrite-loaded waveguide can be increased by 20% or more through the use of mode suppressors that act predominantly on the negative phase-shift "mode." A secondary effect produced by these suppressors is the reduction of the insertion-loss peaks common to this class of phase shifters.

PROBLEM STATUS

This is an interim report; work continues on other phases of the problem.

AUTHORIZATION

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INTRODUCTION

Many applications require continuously variable ferrite phase shifters operating at appreciable average power levels. These power levels have dictated modifications to the longitudinal-field phase-shifter configuration first proposed by Bush (1) and later examined in detail by Reggia and Spencer (2). The original configuration consisted of a ferrite cylinder centered axially in the waveguide. This configuration did not provide an acceptable thermal path between the ferrite rod and a heat sink capable of dissipating the power absorbed by the ferrite. One often-used modification which provides the required thermal path, is obtained by extending the ferrite rod in height so that contact is made between the ferrite and the waveguide walls, which act as heat sinks. This investigation will restrict itself primarily to this case where the ferrite makes contact with the top and bottom waveguide walls. Empirical data will be shown illustrating that changes in the waveguide configuration can be made that will enhance the differential phase shift without degrading the overall performance. In fact, construction tolerances in regard to ferrite-to-metal contact may well be reduced using these modified waveguide configurations.

BACKGROUND

Consider the ferrite-loaded waveguide shown in Fig. 1a, where the ferrite filling the waveguide is divided into two regions: (a) a dotted region adjacent to the waveguide walls and (b) a shaded region centered in the waveguide. A negative phase-shift "mode" is generated by the region (dotted) adjacent to the waveguide walls, while a positive phase-shift "mode" is generated by the centered (shaded) region (3). The resultant differential phase shift is essentially equal to the sum of the phase shifts produced by these two "modes." Removal of ferrite from the region adjacent to the top and bottom walls increases the resultant phase shift which is of a positive sense. However, such an action also removes the heat sink required for operation at higher average power levels. Rather than remove this material, the approach used in this investigation was to suppress the negative phase shift "mode" without removing the ferrite material, which acts as a thermal path to the waveguide heat sink. Heuristically, it was hypothesized that metal side walls placed in contact with the ferrite along the top and bottom dotted regions would tend to partially cut off the negative "mode," while producing only a secondary effect on the positive phase-shift "mode." This mode suppression could be achieved by modifying the waveguide to form a modified "cross" configuration (Fig. 1b) or by locating the pieces of metal adjacent to the ferrite as shown in Fig. 1c. Most of the data to be presented was obtained by using metal inserts to form different cross-waveguide configurations as shown in Fig. 1b.

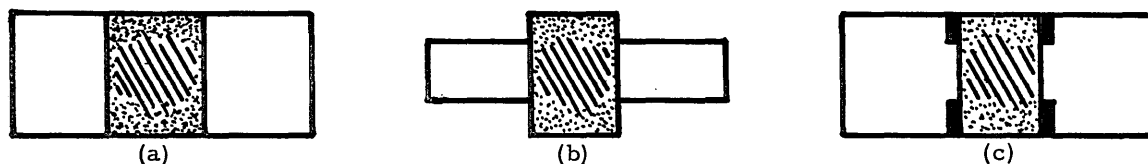


Fig. 1 - Ferrite-loaded-waveguide mode-suppression configurations where the ferrite slab fills the height of the waveguide (longitudinally applied magnetic field)
(a) standard waveguide (b) cross waveguide (c) standard waveguide with "shims"

PHASE-SHIFT ENHANCEMENT

The first step in verifying the action of the mode suppressors (cross-guide configuration, Fig. 1b) at X-band was to compare the differential phase shifts* of the ferrite-loaded-waveguide configurations shown in Fig. 2 when a longitudinal magnetic ferrite was applied. The standard for comparison was the centered ferrite rod (0.250 in wide by 0.400 in. high) located in RG 52/U (0.900 in. by 0.400 in. I.D.) waveguide (Fig. 2a). This rod, which filled the waveguide height, was composed of three sections as shown by the horizontal solid lines. The two pieces adjacent to the waveguide wall had cross sections 0.250 in. wide by 0.100 in. high, while the center section of the center piece was 0.250 in. wide by 0.200 in. high.† When the phase shift of the center piece alone was measured (Fig. 2b), it was of the same sense (positive) but of greater magnitude than that produced by the full-height rod, thus verifying that the phase shift of the center section is positive. Comparison of the phase shift of the two pieces adjacent to the waveguide walls (see Fig. 2c) with the standard verifies that the phase shift is in the opposite sense (negative) and of much smaller magnitude. In fact, the algebraic sum of the phase shifts for this case and the preceding case is approximately equal to the phase shift produced by the standard full-height case (Fig. 2a).

When the standard configuration is converted to the cross-guide configuration (Fig. 2d) by addition of metal inserts (height 0.100 in.), the overall phase shift is still positive and the magnitude is increased over the filled-height case. The phase shift relative to the centered partially filled case (Fig. 2b) may be greater or smaller, depending on the height of the centered ferrite piece and the height of the shims forming the cross guide.

The increase of phase shift when the cross guide is used is attributed to suppression of the negative phase-shift mode. Previous studies have shown that decreasing the height of the waveguide decreases the phase shift produced even though the energy density in the ferrite may be increased. This action was verified by using the 0.250 in. by 0.200 in. piece of ferrite and reducing the waveguide b dimension to 0.200 in., as can be seen by inspecting the phase shift produced by configuration 2e. The last configuration presented (Fig. 2f) concerned replacing the ferrite adjacent to the waveguide walls with dielectric material. This approach was the subject of a previous report (4), and as was expected, the phase shift in this case was less than that of the ferrite-filled waveguide case.

Based on these and similar measurements, it is concluded that the cross-waveguide configuration acts principally on the negative phase-shift mode, thereby increasing the net phase shift.

PHASE-SHIFT ENHANCEMENT VS CROSS-WAVEGUIDE DIMENSION h

Solid ferrite rods ($w = 0.225$ in. and $w = 0.250$ in.) with matching tapers were used in conjunction with the test section and metal inserts shown in Fig. 3. The phase shift obtained for a fixed value of an applied magnetic field is presented as a function of metal-insert height (h) in. Figs. 4 and 5. For each ferrite-rod width ($w = 0.250$ in. in Fig. 4 and $w = 0.225$ in. in Fig. 5), the phase shift increases with increasing h. This increase holds

*A differential phase shift is the change of phase between the demagnetized state and magnetized state. During the remainder of this report, phase shift will be used for differential phase shift.

†This 0.200-in. height was not chosen to produce the maximum possible phase shift but was chosen for illustrative purposes only.

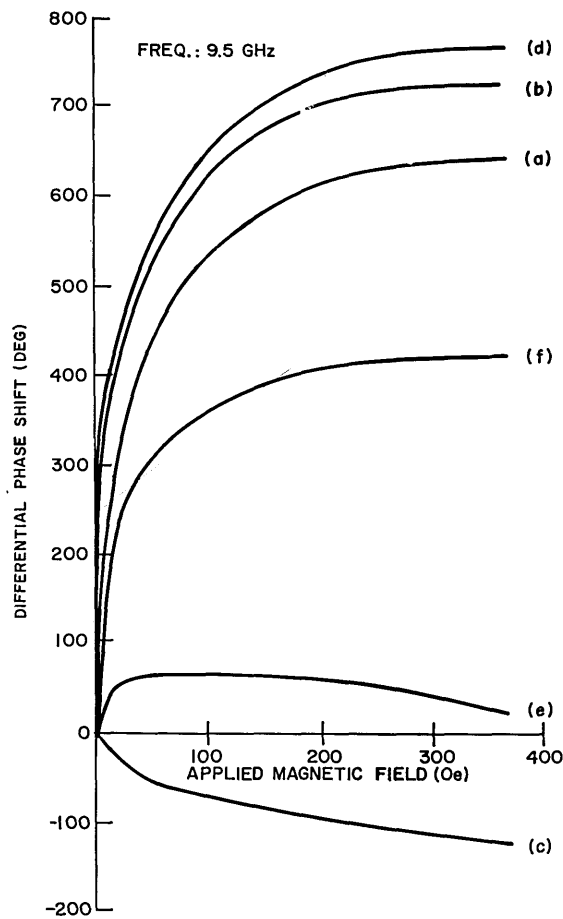
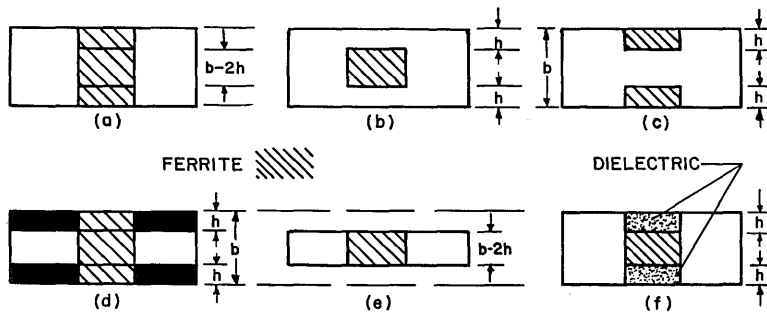


Fig. 2 - Differential phase-shift dependence on applied magnetic field for six waveguide configurations. In all cases the ferrite-slab width is 0.250 in. and the applied magnetic field is along the waveguide axes.

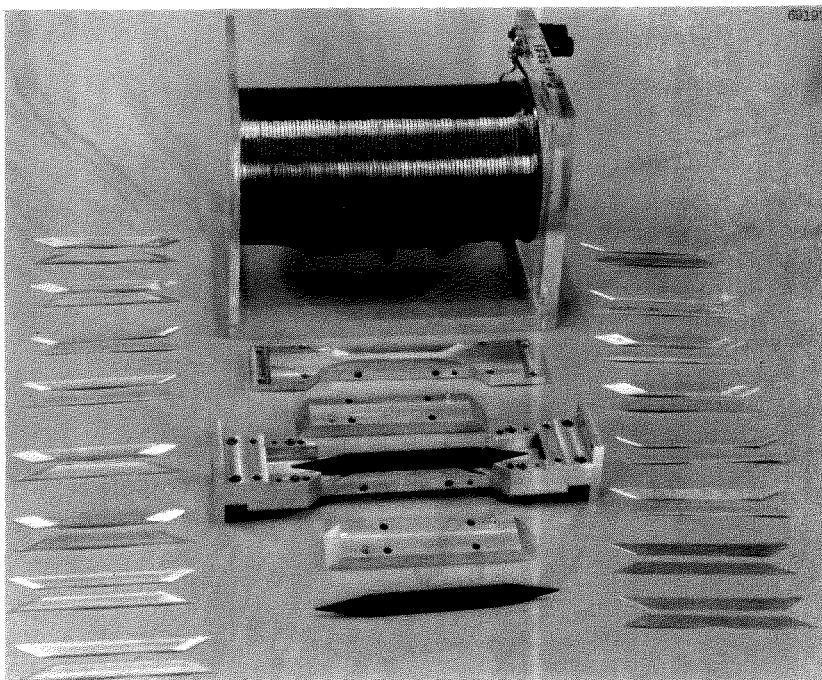


Fig. 3 - Cross-waveguide test sections

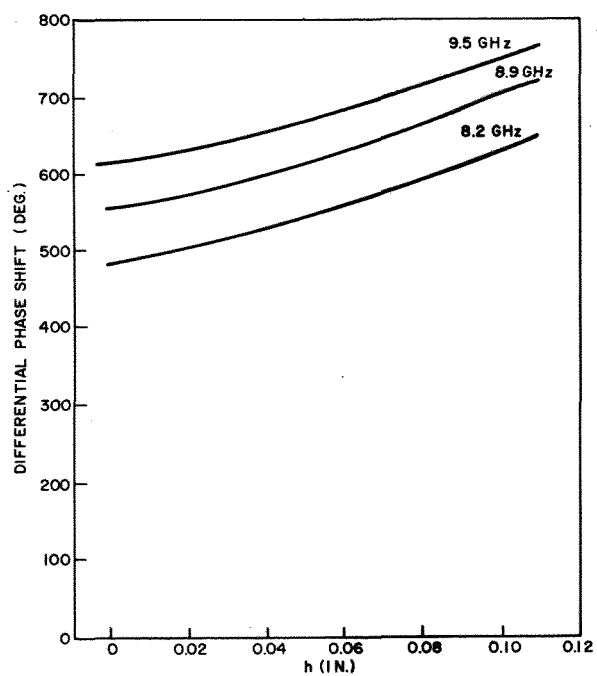


Fig. 4 - Differential phase-shift dependence on cross-waveguide dimension h when the ferrite-rod width is 0.250 in. The applied magnetic field is 160 oe.

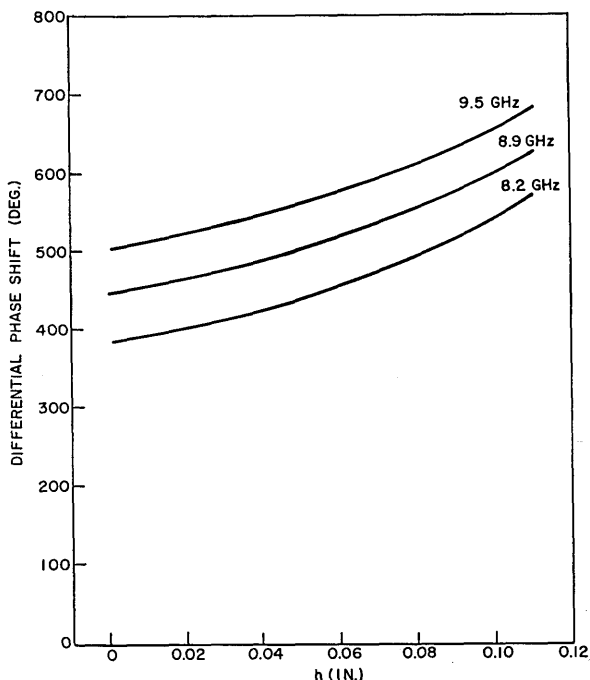


Fig. 5 - Differential phase-shift dependence on cross-waveguide dimension h when the ferrite-rod width is 0.225 in. The applied magnetic field is 160 oe.

over the frequency region of interest and typical performance is shown for three specific frequencies within this region. While not shown, similar curves displaced vertically downward were obtained for the $w = 0.250$ in., one-half-height ($b = 0.200$ in.) waveguide.

While Figs. 4 and 5 show phase shift increasing with h , the full range of h is not, in practice, available for use. It is felt that, at some point, the inserts will interfere with the positive phase-shift "mode." Insertion loss and VSWR may well be used to establish this upper limit on h .

LOSS AND VSWR VS CROSS-WAVEGUIDE DIMENSION h

In practice, an analog phase shifter of the type under investigation would probably be operated between the demagnetized state and a magnetized state producing less than the maximum possible phase shift for the particular ferrite-waveguide configuration. At a given frequency the insertion loss will vary as the magnetic field is varied. When insertion loss is studied as a function of frequency, the maxima and minima points form two curves enclosing all values of loss that would be encountered using the device over the magnetic-field values specified. In this report, the area enclosed by these curves will be termed the loss envelope.

In Fig. 6 the insertion-loss envelope and maximum VSWR are presented as a function of frequency for the solid ferrite rod of 0.250-in. width, as defined in Fig. 2d. The applied magnetic field used to obtain these curves was varied between the demagnetized state and 160 oe. At 160 oe, approximately 90% of the maximum phase shift is obtained.

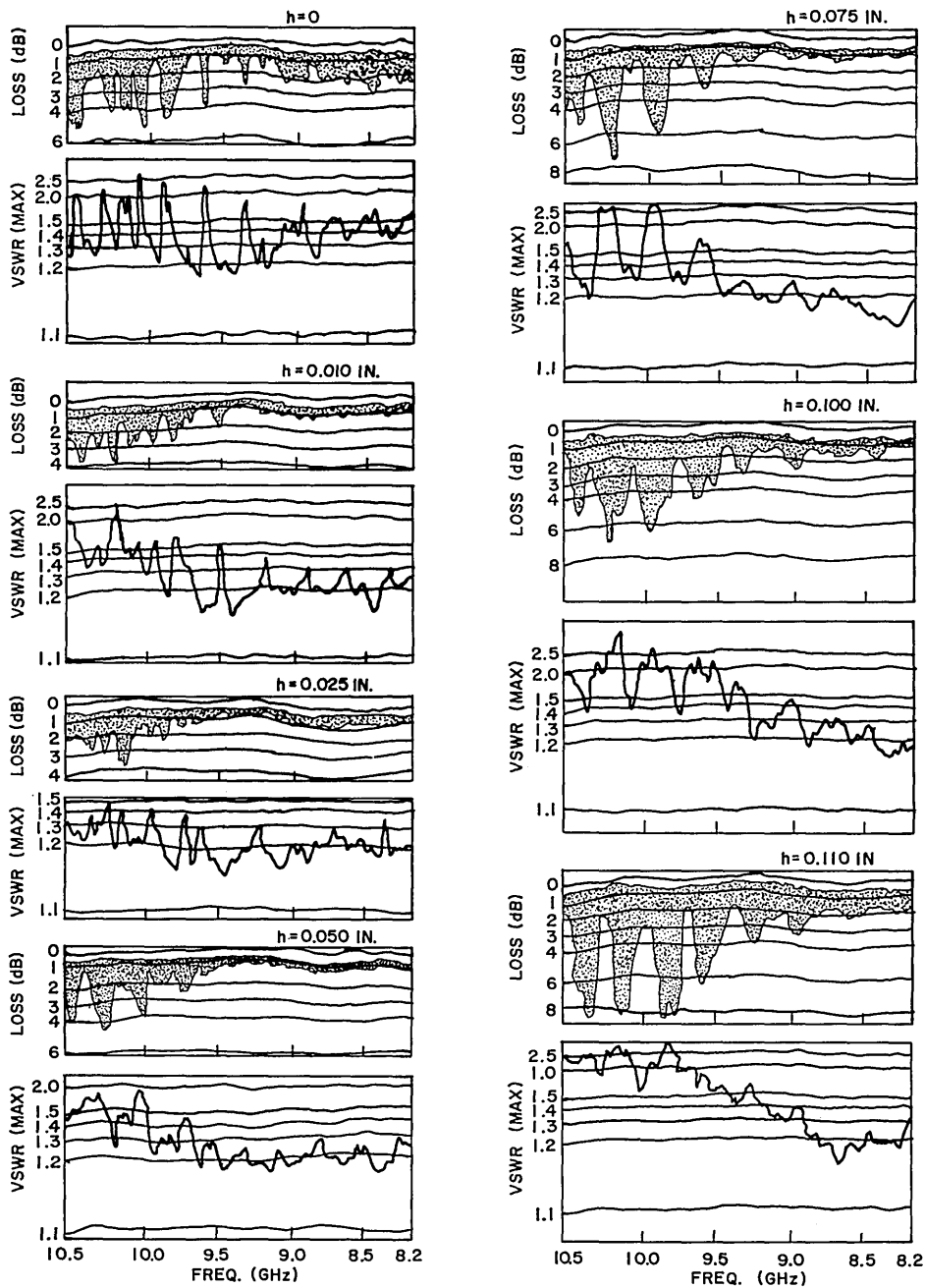


Fig. 6 - Insertion loss and VSWR dependence on cross-waveguide dimension h when the ferrite rod is 0.250 in. wide

When the standard configuration (Fig. 2a) was investigated, there were only small frequency regions of satisfactory loss and VSWR. These regions could have been extended by a combination of closer tolerances and avoiding air gaps; however, in view of the preceding results, this was not felt necessary. Conversion of the ferrite-loaded standard waveguide to cross waveguide produced the following trends for values of h up to from 0.050 in. to 0.075 in.: (a) reduced the size of the insertion-loss envelope for the frequency range 9.5 to 8.2 GHz, (b) reduced the maximum VSWR over this region, and (c) increased the phase shift per unit length (Fig. 4). For values of h falling within the region 0.075 in. to 0.100 in., it seems that the cross waveguide interferes with the positive phase-shift "mode," thereby increasing the insertion loss and causing an increase in the VSWR.

When the 0.225-in. ferrite rod is used, similar insertion loss and $VSWR_{max}$ characteristics are present as can be seen from Fig. 7. In this figure the bandwidth is extended to a higher frequency, as would be expected using a narrower ferrite width. Based on the data in both this and the preceding figure, plus a survey using the configuration of Fig. 1c, the maximum tolerable value of h is directly related to the width of the ferrite. The narrower the ferrite, the smaller the value of h that can be used in practice.

SUMMARY

The cross-waveguide configuration has been shown to increase the phase shift of a class of ferrite-analog phase shifters. Increases of approximately 20% have been obtained, while the thermal characteristics of this phase shifter have been maintained or improved. Small, if any, detrimental effects have been introduced by the cross-waveguide configuration as far as insertion loss and VSWR are concerned. In fact, it appears that certain tolerances, connected with the waveguide-to-ferrite contact, can be reduced.

Future work on this configuration will include consideration of (a) the high-peak-power characteristics in regard to loss and (b) additional studies of the ferrite width (w) vs allowable values of h .

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REFERENCES

1. Bush, D., Proceedings of the Institution of Electrical Engineers, Part B, 104(No. 4): 368-369 (1957)
2. Reggia, F., and Spencer, E.G., "A New Technique in Ferrite Phase Shifting for Beam Scanning of Microwave Antennas," Proc. I.R.E. 45:1510-1517 (1957)
3. Snieder, J., "Influence of μ and κ on the Reciprocal Phaseshifter as a Function of Position in the Waveguide," Physics Laboratory of the Natl. Defense Research Organization TNO (Netherlands), Report PL1965-19, Apr. 1965
4. Reuss, M.L., Jr., "A Study of a Ferrite Phase Shifter," NRL Report 6112, June 8, 1964

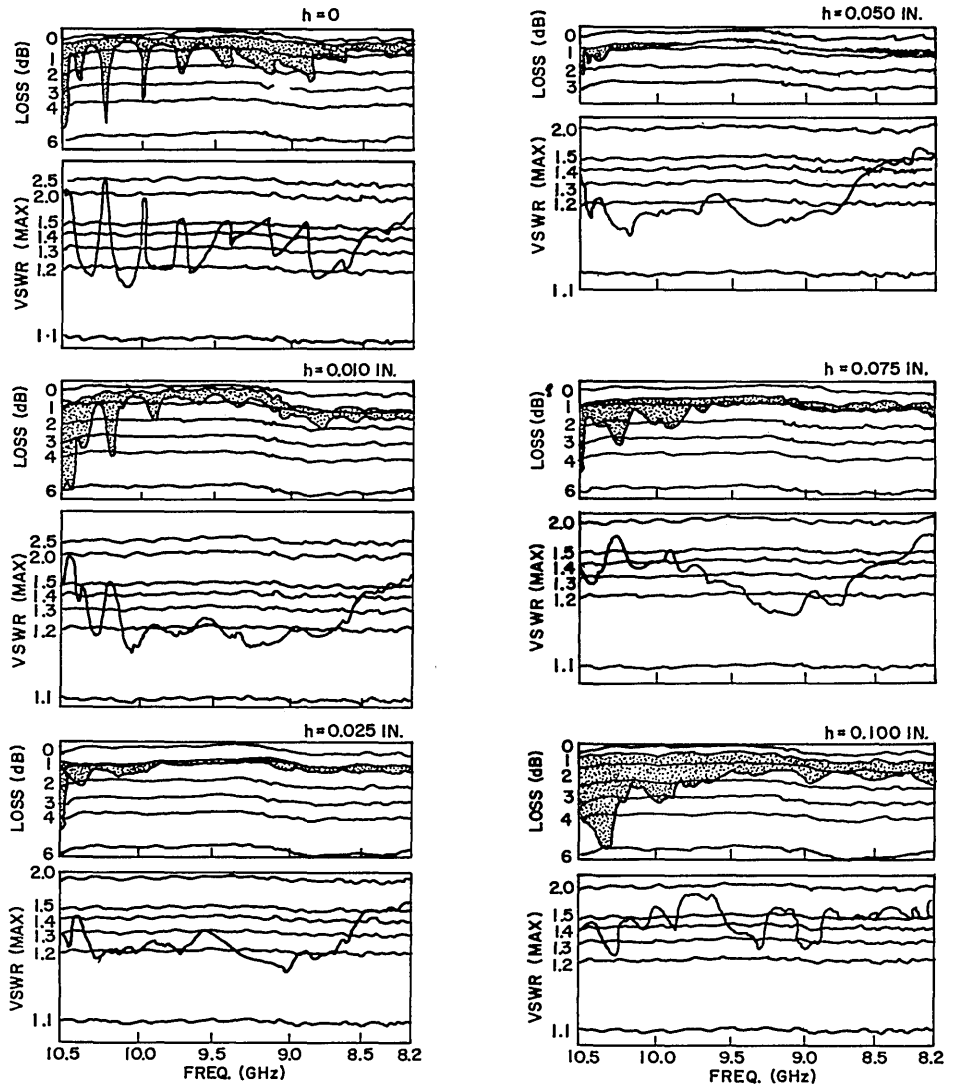


Fig. 7 - Insertion loss and VSWR dependence on cross-waveguide dimension h when the ferrite rod is 0.225 in. wide

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